LEGOS AND AERONAUTICS IN KINDERGARTEN THROUGH COLLEGE

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Abstract

The purpose of this paper is to introduce the idea of teaching engineering as a method of improving science literacy in adults. In the paper, we present curricula designed for both elementary school students and college-level students. We target elementary school students because they have not yet formed stereotypes and are eager to learn engineering. The college-level curriculum is designed for students pursuing elementary education certification and liberal arts students as well as first-year engineers. In particular, the lessons center around aeronautics and use LEGO bricks for building and testing. We couple the LEGO designs with LabVIEW™ control software to incorporate computer control and measurement. Student, teacher, and parent response to both curricula has been positive and enthusiastic. We are currently working on using engineering as a common thread throughout the science curriculum in elementary education.

Introduction

Although few adults would proudly say "I cannot even read a newspaper", one often hears "I cannot even balance my checkbook". One can admit to not being able to do simple arithmetic and get murmurs of agreement from the crowd. Adults will - almost proudly - admit to being baffled by torque because they are "not a science type," whereas no one readily admits to not understanding the newspaper because they are "not a literary type". Why is it acceptable that people can graduate from college and not grasp that an object at rest has forces acting on it? Current scientific and mathematics illiteracy among Americans can be linked with the science emphasis in the early years. Science is often taught by a separate instructor, brings with it negative stereotypes, and gets little emphasis in comparison with reading skills in the formative elementary years. Further, many of the science curricula show little coherence from year to year. Where one year a teacher might get the students interested and involved with a science curriculum on motion and simple machines, the next year, their science might be limited to the study of birds.

Over the past six years, at Tufts University we have worked with over 30 schools and over 200 teachers, developing innovative ways of bringing science into the classroom. Bringing it in as a subject that has close links with the other subjects they learn. The most effective method we have found to do this is not to teach science, but rather engineering. Using engineering to draw the students in, one can motivate the students to learn the underlying science. Further, engineering gives the students a unifying theme to their science curriculum from year to year, without limiting the diversity in the taught scientific subjects. For instance, simple machine units fit nicely in with engineering design, whereas weather units rely on the same science principles found in fluids engineering. Environmental engineering requires knowledge of biology and chemical engineering can be used to introduce simple chemistry concepts.

What is the advantage of using engineering as a way of motivating the students in science education? Most children tend to be engineers initially, before frantic parents cap their creativity with a screwdriver. Kids love to build - hence the popularity of blocks, trains, and doll houses. They spend much of their time creating, or designing, new structures or new setups. They discover on their own concepts such as torque or force, without naming them as such. This sort of play, however, is rarely associated with science - one is fun, the other is "nerdy". By capitalizing on this desire to build, we have worked with teachers from kindergarten to college to get more "non-science types" to at least understand some the fundamental concepts in science. In particular, in the work presented here, we based most of the curriculum around the airplane. Our long term goal is to increase science, math, and engineering literacy in adults: from increasing awareness at the kindergarten level, through teaching liberal arts students at the college level.

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Aeronautical Engineering in the Elementary School

Elementary school students have little difficulty grasping the necessary fluid mechanics to explain the principles of flight. Although they have often not formally learned about a lift force, most have stuck their hand out of the window of a moving car, varied the angle of attack and felt the lift. We start the unit by explaining the difference between force an pressure. This is done most effectively with a common nail. By pressing first the nail head then the nail tip, with equal force, against their finger, they quickly learn the effect of area. By asking simple questions, the teacher can have the student "discover" this relationship between pressure and force. Bernoulli's equation is, perhaps, the most advanced concept because they have to understand energy conservation (or how to integrate forces - the former being the easier of the two). We teach this through a number of hands-on demonstrations and group discussions. Blowing over a piece of paper - or under a piece of paper held aloft by two books - works well in these discussions. The all-time favorite, however, is the water sprayer. By blowing over the top of a straw (partially submerged in water), one can create enough of a pressure drop to lift the water up out of the straw and spray it at one's neighbor. Finally, paper airplanes give the students the opportunity to test out some of these science concepts in a true engineering fashion. One can "see" force as the plane moves up or down. Torque, too, is visible as the plane rolls. One can get a full listing of the experiments at our World Wide Web site at http://ldaps.ivv.nasa.gov (figure 1) or from a number of commercially available science experiment books.

Engineering with LEGO Bricks in the Elementary School

Aeronautics Curriculum

There are two difficulties with the previously outlined curriculum. First, like many others, it is lacking in a coherent theme - the students do this month (or less) unit on airplanes and then move on to geology. Second, most of the experimentation uses existing materials (straws etc.) - limiting the creativity on the part of the student. We, therefore, have expanded the program to allow for more creativity and more interaction with future science curricula. We do this through LEGO building blocks.

LEGO bricks are often a child's first experience with engineering design. Frustration of falling LEGO towers or crashing LEGO bridges often is the child's first adventure with forces and torques. The LEGO bricks have a number of advantages as a pedagogical tool. First, the students (almost without exception) enjoy playing with them and are familiar with them. Second, the capability of the bricks ranges from simple (DUPLO brick stacks) to highly complex (Technics cars with steering and shock absorbers). Third, they allow creativity on the part of the teacher and the student. The

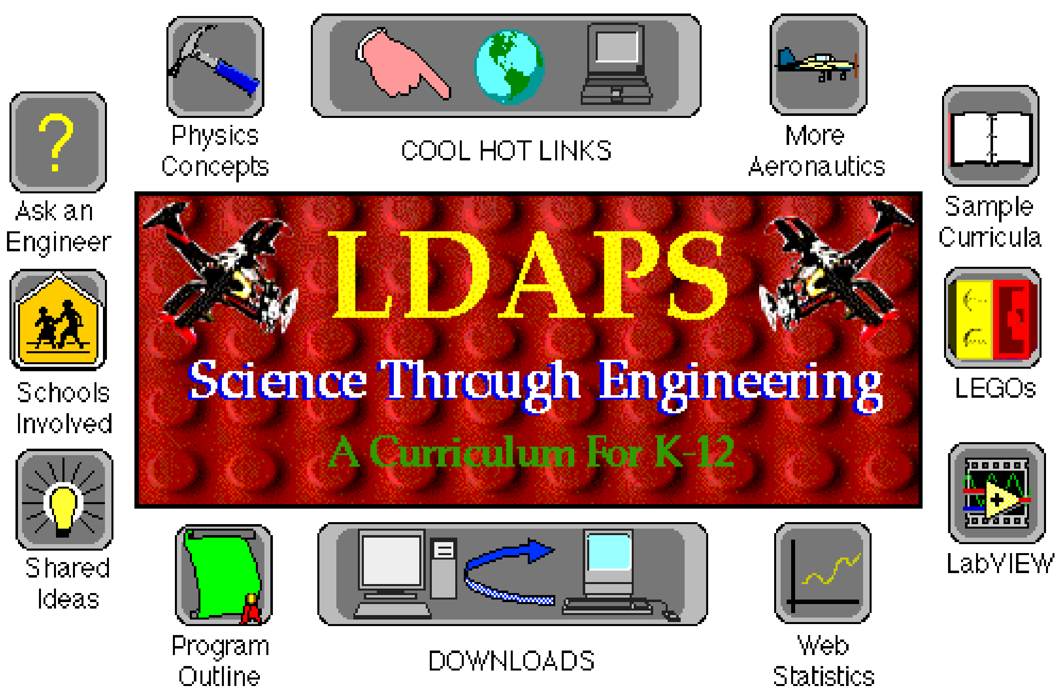

Figure 1: http://ldaps.ivv.nasa.gov

curriculum can change year to year - without requiring the purchase of new materials. Fourth, they can be interfaced with a computer to make the construction project "come alive". And fifth, they can be stored in very little space.

Although LEGO bricks can be used to teach almost every aspect of engineering - from building a solar house to an electric drill, we use them mostly to build airplanes. Figure 2 is a picture of some of the simplest airplanes one can build. The plane on the left was built by a preschooler and the one on the right by an adult. Both designs are similar to a conventional aircraft, having large lifting surfaces and some form of control. The preschooler's craft, however, shows more innovation in design and emphasizes the propulsion system. Both of these designs can be mounted on a LEGO test stand and placed in a wind tunnel. Figure 3 shows the portable tunnel we use. Plans are available from the web site. Using the LEGO computer interface, one can actually automate the test stand. This allows the user to vary the aircraft angle of attack and look at the change in lift. At this point, students are usually fervently defending the abilities of their airplane and, with careful guiding from the teacher, will "stumble" on the concepts of lift, drag, stall, weight, etc.

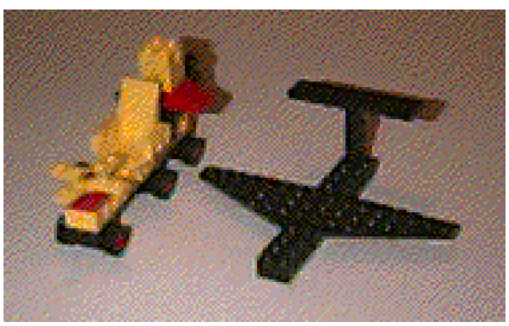

Figure 2: Possible Simple LEGO Aircraft Designs

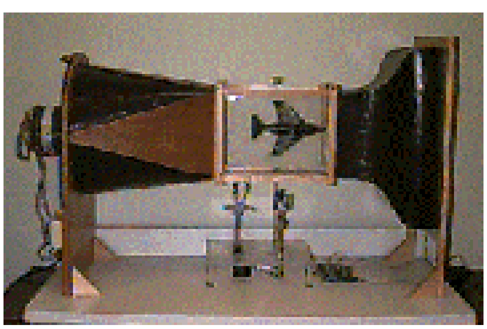

Figure 3: The Wind Tunnel

At the other extreme, the airplanes in the title section of figure 1 show an all LEGO aircraft with full aileron and rudder control. Coupled with a LEGO joystick, students can "fly" the plane in the wind tunnel. Now concepts such as force and torque are apparent and the teacher can start discussions of control and stability. At this point, the teacher can lead the discussion into other types of aircraft and spacecraft. Jet fighters and rockets are usually popular, as are fish and birds. Since fish are often aerodynamically designed for high speed swimming (with the Bluefin Tuna among the fastest), they share many features in common with aircraft.

Thematic Approach

Although the LEGOs are fun and exciting and can be used to teach the science and engineering principles, the curriculum described above is still disjointed from the previous and future science unit taught in the classroom. Students need to see that all science and engineering is intertwined in that any one subject builds off of concepts learned in any other. Further, all the subjects require mathematics, reading and writing skills, and can be closely linked with the other classroom disciplines. That is, the science curriculum for a K-6 school should have a common theme or thread running through it as well as a cross-curriculum flavor, so that the student realizes these inter-dependencies. We use the concept of engineering design and the LEGO building blocks as the basis for this common thread.

Our future plans are to have a student build with the LEGO blocks every year in the elementary school, each year adding more skills to the project. In kindergarten, the students start to associate the phenomena with the terms: force, torque, etc. This can be done with the larger DUPLO blocks or the more complicated LEGO blocks. The larger blocks have the advantage one can build big things faster. The smaller blocks have more complexity and capability but are more difficult to manipulate. Teachers can use the blocks as math exercises as well, counting knobs on the blocks. Finally, teachers can integrate reading and writing skills through creative stories based on the block designs as well as written comparisons of various designs.

The first and second grades can add the computer component, with the students using existing code. This allows them to make their objects move and introduces concepts of sensors and controls. Top students in these grades can start developing their own simple programs, such as making cars that sense the proximity of a wall and stop before crashing into it.

Each of the sequential three grades can add complexity to the overall setup, with classes making small towns with operational stop lights and streets. Typical subjects of weather, electricity, and simple machines all fall very nicely into this LEGO/computer environment. Using LEGO sensors, students can make their own weather station. Coupled with a connection to the World Wide Web, they can compare their readings to those of weather stations across the country. Electricity combines nicely with the LEGO sensors - using the outputs to drive motors and lights and the inputs to sense current conditions. Finally, the LEGO pulleys and gears allow the students to build their own simple machines and compare their designs to existing ones.

To date, we have done very little work bringing these curricula into the older grades. The main reason is by 7th and 8th grades, the students have already stereotyped themselves as “techie” or “non-techie” types. By concentrating our efforts in the elementary years, we aim to decrease the use of these stereotypes by making science and engineering as natural as reading or writing.

LEGOs and Aeronautics at the College Level

Curricula developed for elementary schools often provides an excellent foundation for classes at any age level. We have successfully used this curriculum described above in a number of college-level courses. In keeping with the general goal of this work, the two courses described below are specifically developed for the liberal arts major and - more importantly - the next generation of elementary school teachers.

Two years ago, Tufts initiated an innovative approach to the engineering curriculum by introducing a set of new elective courses. These courses are designed specifically for the first-year engineering student, the liberal arts major who has an interest in engineering, and the graduate students who are training to become teachers (pre-service teachers). The course content changes year to year and reflects the current interest of the individual faculty member. They range from how to design and build a musical instrument to how animals have engineered solutions to take advantage of their environment. These courses have been very popular among the engineering and liberal art students alike.

The first introductory course that used the aeronautic curriculum was a course on Aircraft and Space Systems. This course emphasized aircraft design to teach basic fluid mechanics and physics. Probably the most unique aspect of the class is that it was almost entirely taught through hands-on experiments. The students were given a brief introduction of the concept. After the introduction, they were given a number of demonstrations they did individually and tried to - as a group - define the concept. For instance, we taught torque by giving the students a five minute introduction to the concept and then giving them small balsa airplanes which they could modify to cause roll. They then discussed what they saw in a group and defined torque through their observations. After the groups combine together with a final definition, we then introduce the math behind the concept - moving from qualitative to quantitative. Finally, we give them an open-ended design problem at the end that makes use of their newly acquired knowledge. We do this with the concepts of force, torque, friction, energy, pressure, and end with Bernoulli’s equation. At this point they have the physics background to start designing. The final project for the class is the complete design of an airplane, estimating the aircraft performance and limitations.

The second introductory course emphasizes the LEGO bricks as a teaching tool. Entitled “The Way Things Work,” it is based on the famous book by David Macaulay and teaches through taking machines apart. We then use the LEGOs to replicate the existing technology (for instance a suspension bridge). The LEGO bricks start to teach the students the complexities of three-dimensional design. This course also introduces the concept of process control (both passive and active) as well as fundamental data acquisition concepts. We elaborate on these ideas in a required junior-level course on experimentation, where the students actually build and program a LEGO-based 10 bit gray scale scanner. Some students take the project even farther in their senior year in their senior design project. One group last year built and programmed a three-dimensional CNC milling machine. For their final demonstration, they cut out the hull of a sailboat out of balsa wood.

LEGO Block Capabilities

Control Lab Box

The Control Lab box allows the LEGO sensors to the computer. It has an integrated data acquisition board (10 bit resolution), interfaced through the RS-232 port. Figure 4 shows a picture of a box. Note that there are 8 output (black) sensors, four yellow input sensors (temperature and touch), and four blue (digital information) inputs. These inputs can be modified to accept non-LEGO sensors as well - with 10 bit accuracy.

Sensors

LEGO currently markets four sensors: touch, temperature, light, and angle sensors. The touch sensor

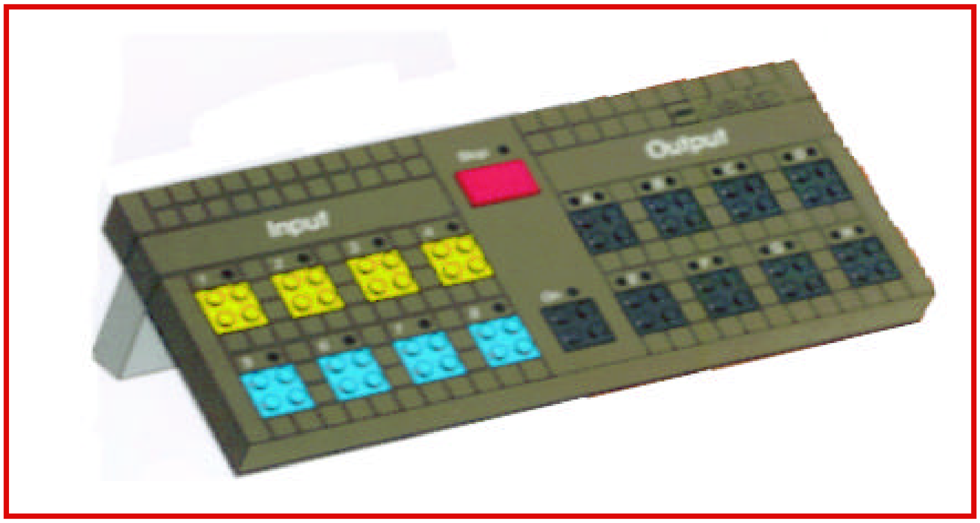

Figure 4: LEGO Control Lab Interface Box

is a simple switch built into a brick. The temperature sensor measures temperatures from - 20°C to 50°C. The light sensor has a built in red diode as a light source and reads illumination in all wavelengths. Finally, the rotation or angle sensor measures rotation in 1/16 of a rotation increments. Figure 5 shows all of the sensors.

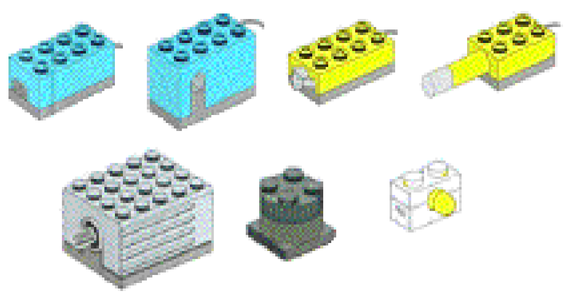

Figure 5: Available LEGO Sensors: light, angle, touch, temperature, motor, sound, and light

Limitations

The Control Lab Interface box has the advantage that it is an inexpensive, simple, multi-platform data acquisition system. It does, however, have a number of limitations. First, since it is a serial interface, one has no control on sampling rates. It samples each channel at roughly 60 times a second. Second, its current configuration is not built for non-LEGO sensors. In order to use non-LEGO sensors, one must make a number of modifications. This should change in future setups. Third, it has a limited number of possible output voltages (16) and no counter and digital I/O capabilities. One must remember, however, it also only costs $250. At this price, it has an impressive range of capabilities. We have developed a LabVIEW ™ software interface for the LEGO Control Lab Box allowing advanced data manipulation. Figure 6 shows a sample code which runs a motor for a predefined amount of time. We use the LabVIEW™ interface for two reasons: it is easy to use and easy to learn. Since it has essentially no syntax, students can program by pattern recognition without knowing how to read and write.

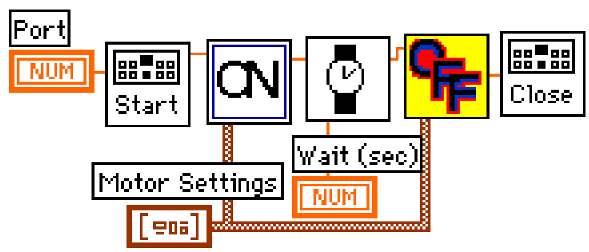

Figure 6: A Sample LabVIEW™ Diagram

Student and Teacher Response

Elementary Level

The response in the elementary school has been promising. The aeronautics curriculum (without LEGOs) has been taught in every grade from Kindergarten to college. Local engineers have used it with boy scout troops, all-female schools, and after-school science shows. Engineers and teachers from as far as Hawaii have brought parts of the curriculum into their local schools. The LEGO component is relatively new but has been met with much excitement on the part of teachers, students, parents, and local volunteers.

The students enjoy the hands-on nature of the curriculum. Their natural desire to build, coupled with their curiosity and creativity has led to some interesting - and often surprising designs. It is difficult to access how the curriculum has influenced them, although teachers in the following years have noted an increase in science interest.

College level

The aeronautics and LEGO bricks were very well received by the students. Over 60% of the students have ranked the courses at the top (5/5). About one-fifth of the introductory courses were non-engineers. 70% of the students involved with the LEGOs felt that they were learning from using the LEGOs (only 1% did not like the LEGOs). The bulk of the class felt that the material they learned in the various classes would be useful in other classes, and most of the students were interested in sequel classes.

Conclusion

In conclusion, the idea of teaching science through engineering is very appealing. Students of all ages enjoy the hands-on nature of the engineering. Difficulties in the engineering design motivate these students to learn the underlying physics - sparking interest in the science. Teachers like the engineering-based curricula because it gives the students the opportunity to exercise creativity and teach themselves.

An interesting facet that we are still working to address is the role gender plays in societal miss-conceptions of "the engineer." A number of years ago, we were running a teacher workshop at Tufts. Teachers were split into groups of four and were teamed with a Tufts engineering graduate student. They were asked to figure out how a toilet works by taking it apart. One of the Tufts graduates was female. With almost unfailing repeatability, her group of teachers (male and female) would ask the neighboring graduate student (male) technical questions. These teachers knew that she was an engineering graduate student yet instinctively they went out of their way to ask a male the technical questions. Why? Why is it that up until 8th grade, the top science students in the classroom tend to be female, yet the number of females entering science and engineering degrees is substantially less than their male counterparts? There are numerous possible reasons, although it is difficult to prove or disprove any one. Cambell and others claim that girls and boys learn differently. For instance, boys seem to learn better in competitive environments whereas girls prefer collaborative learning. Boys tend to act first and think later, whereas the actions of the girls tend to be premeditated. Another possibility is that the first male teachers they have are often upper elementary science teachers, thus insufficient numbers of female role models could have an effect.

Acknowledgements

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References

Bailey, S. L. Burbidge, P. Campbell, B. Jackson, F. Marx, and P. McIntosh, *The AAUW Report: How Schools Shortchange Girls.* Washington DC., AAUW Educational Foundation and NEA, 1992.

Pols, Y., C.B. Rogers and I.N. Miaoulis, *Making Eighth Grade Science Exciting Through Aeronautics*, Int. Jrnl. Engng. Ed., Vol. 83, 3, 243, 1994.

Macaulay, David, The Way Things Work, New York: Houghton Mifflin, 1988.

Kaput, J. J., *Technology and Mathematics Education,* in Radical Constructivism in Mathematics Education (E. von Glasersfeld ed.) Boston: Kluwer, 1991.

Lehrer, R., J. Littlefield, B. Wottreng, and N. Youngerman, Seeding mindstorms: Using Logo in the Elementary Classroom, Fontana WI: B & B Publishing, 1993.